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R.E. Smith

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16. ABSTRACT

For many years California has used cement treated base materials under asphalt concrete because of its strength and economy. However, any shrinkage cracking in the base tends to reflect through the paving. Surface water may then intrude and cause failures of the highway due to loss of stability in the supporting material. The most common remedial action taken is to seal these cracks with an asphalt compound. This sealing operation not only is costly but also results in some reduction in the riding quality as well as appearance of the roadway (Photo 1). Thus, the reduction or elimination of shrinkage cracking of cement treated base (CTB) is desirable.

A review of data gathered in a prior field investigation of CTB shrinkage cracking (1) indicated that certain aggregates had a consistent tendency toward high, moderate, or low cracking. These aggregates were studied with respect to mineral content, surface area, and absorption.

A laboratory test to measure the shrinkage of cement treated specimens was developed. When these same aggregates were tested, a positive correlation was found between laboratory and field shrinkage. This made it possible to conduct studies in the laboratory on the primary design and construction variables such as the amount type of cement, moisture, density, etc.

The shrinkage test was also used to evaluate several potential additives for use to reduce pavement cracking due to shrinkage in the cement treated base.

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A LABORATORY STUDY OF FACTORS AFFECTING THE SHRINKAGE CHARACTERISTICS OF CEMENT TREATED BASE

Summary Report by: R. E. Smith

Investigators: D. L. Durr
R. N. Doty
D. H. Andersen
H. D. Sterner

Supervised by: G. B. Sherman

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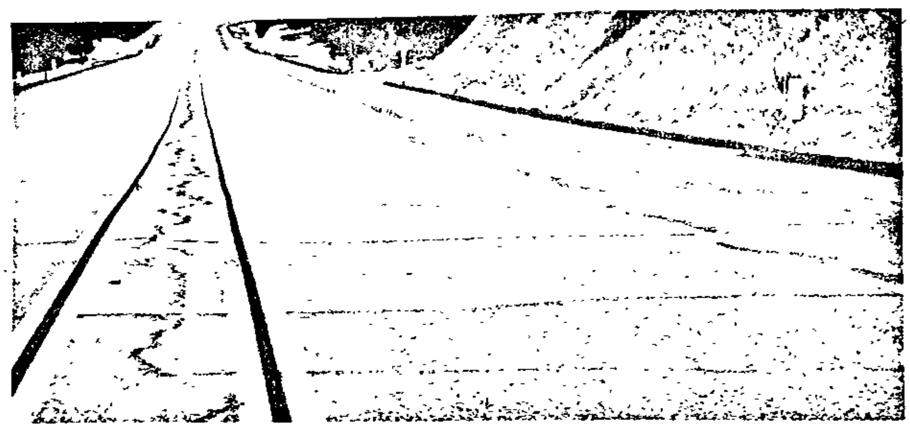
INTRODUCTION

For many years California has used cement treated base materials under asphalt concrete because of its strength and economy. However, any shrinkage cracking in the base tends to reflect through the paving. Surface water may then intrude and cause failures of the highway due to loss of stability in the supporting material. The most common remedial action taken is to seal these cracks with an asphalt compound. This sealing operation not only is costly, but also results in some reduction in the riding quality as well as appearance of the roadway (Photo 1). Thus, the reduction or elimination of shrinkage cracking of cement treated base (CTB) is desirable.

Photo 1



Pavement Distress Caused by Shrinkage
Cracks in Cement Treated Base

A review of data gathered in a prior field investigation of CTB shrinkage cracking[1] indicated that certain aggregates had a consistent tendency toward high, moderate, or low cracking. These aggregates were studied with respect to mineral content, surface area, and absorption.

A laboratory test to measure the shrinkage of cement treated specimens was developed. When these same aggregates were tested, a positive correlation was found between laboratory and field shrinkage. This made it possible to conduct studies in the laboratory on the primary design and construction variables such as the amount and type of cement, moisture, density, etc.

The shrinkage test was also used to evaluate several potential additives for use to reduce pavement cracking due to shrinkage in the cement treated base.

CONCLUSIONS

1. The standard test for mineral content, absorption, and surface area of aggregates used in cement treated base (CTB) do not appear to be significantly correlated with the pavement shrinkage cracking.

2. The shrinkage test developed in this research can be used to estimate the shrinkage cracking potential of a given cement treated base.

3. There is no significant difference in the amount of shrinkage that occurs in CTB when Type I (general purpose) cement is used in lieu of modified Type II (moderate sulfate resistant) cement.

4. There is no significant difference in the shrinkage that occurs in CTB if cement contents between 2-1/2 and 6 percent are used, or if the relative compaction varies between 90 and 100 percent.

5. A variation in moisture content of 2 percent above or below optimum has no significant effect on CTB shrinkage.

6. Some of the chemical additives reduce, shrinkage, but this is accompanied by a proportional loss of strength. The use of these additives to reduce shrinkage cracking in cement treated base is not recommended.

RECOMMENDATIONS AND IMPLEMENTATION

Implementation will consist of formalizing the shrinkage test for cement treated aggregates, and adoption as a standard California test method.

It is recommended that shrinkage testing be conducted on new aggregate sources. Also, supplementary shrinkage testing should be conducted on aggregates used in roadways which exhibit an unusually high or low crack frequency due to shrinkage of the cement treated base.

DISCUSSION

Background

Data accumulated during a 1967-68 comprehensive survey of the performance of cement treated bases in California[1] indicated that shrinkage cracking was much more severe on some projects than on others. Those factors which appeared to most strongly influence the frequency and severity of the shrinkage cracking observed were reported as: (1) the type of mixing operation (plant mixed CTB contained less severe and less frequent cracking than did road mixed CTB), (2) the geographic location (less cracking on jobs constructed in relatively humid climates with relatively little annual temperature change), (3) the thickness of the asphalt concrete (less cracking under thicker AC), and (4) the thickness of the lifts of the CTB (two lifts of 0.33' thickness contained fewer and smaller cracks than did one lift 0.67' thick).

Several other factors were also examined at that time appeared to have little or no influence on the severity and frequency of the shrinkage cracking observed. These additional factors were: cement content of the CTB, cement type, basement soil R-value, gradation and sand equivalence of the CTB aggregate, compressive strength and relative compaction of the CTB, time interval between placement of the CTB and the AC, roadbed drainage, and relative traffic intensity sustained prior to the field review of the structural section. Thus, although distinct differences in cracking frequency had been observed between jobs, no definite factors could be consistently assigned as causes of this CTB shrinkage variation.

Aggregate Sources vs. Shrinkage Cracking

The initial phase of the project was directed toward selecting and obtaining aggregates used in roadways displaying varying degrees of shrinkage cracking. Information included in the previously cited survey of cement treated bases[1] indicated that the normal average interval for transverse shrinkage cracks is approximately 20 feet. There was, however, a wide range in observed crack frequency. On some roads, cracks were found at intervals of five feet or less, while on other roads no cracking was visible. From the accumulated information it was possible to identify several sources of aggregate which had an apparent high potential for excessive shrinkage when treated with cement, as well as some aggregates which apparently had very little potential for shrinkage when treated with cement.

Those aggregates chosen for use in this study were taken from the same sources used for the construction of roadways containing shrinkage cracks at average intervals of from 0 to 20 cracks per 100 lineal feet. A brief description of the approximate location of each aggregate source and the frequency of the cracking observed in the roads for which they were used are included in Table 1.

TABLE 1

AGGREGATE SOURCES

Aggregate No.	Location of Source	Average Crack Frequency per 100 Lineal Ft. (ACF)
1	Ten Mile Creek, Mendocino Co., N of Laytonville	20
2	Forsythe Creek, Mendocino Co., N of Ukiah	20
3	Outlet Creek, Mendocino Co., E of Longvale	10
4	Sacramento River, Shasta Co., N of LeMoine	8.5
5	Gravel deposit, San Joaquin Co., S of Tracy	6.5
6	Churn Creek, Shasta Co., E of Redding	6.5
7	Anderson Creek, Shasta Co., W of Anderson	6.5
8	Hillside quarry, Contra Costa Co., near Orinda	5.0
9	Sacramento River, Tehama Co., N of Los Molinos	0
10	Gravel deposit, El Dorado Co., S of Placerville	0
11	San Gabriel River, L.A. Co., near Irwindale	0

Aggregate Properties vs. Shrinkage Cracking

Samples of ten of the selected aggregates were analyzed for mineral content. The mineral content as tabulated in Table 2, is estimated on the basis of X-ray diffraction and differential thermal analysis (DTA). The absorption and the surface area of the aggregates were determined using a modified Centrifuge Kerosene Equivalent (CKE) procedure[2].

The surface area of the passing No. 200 portion was also determined by the Glycerol Retention Test Method proposed by Diamond and Kinter[3].

These properties are tabulated in Table 2, together with the observed cracking frequency. No apparent significant relationship was found to exist between mineral content, absorption, or surface area and the frequency of cracking.

Also tabulated is a quantity termed "Percent Shrinkage". This value is determined by the linear shrinkage test, which is discussed in the following sections. However, it is noted that a significant correlation did not appear to exist between the factors studied and the shrinkage test results.

TABLE 2

MINERALOGICAL AND PHYSICAL PROPERTIES OF AGGREGATES

Aggr. Number	*** ACF	Percent Shrinkage	MINERAL CONTENT* (Percent) X-ray Diffraction & Differential Thermal Analysis A	B	C	D	E	F	G	H	I	J	K	L	M	Absorption Modified CKE (Percent)	Modified CKE (sq.ft./lb.)	SURFACE AREA Glycerol Retention (sq.m./gm.) Int.	Ext.	Total
1	2.0	0.108	40	16	0	3	0	0	8	3	6	10	0	0	4(N)	0.9	47	31	14	55
2	2.0	0.102	42	22	5	0	0	0	8	T	5	1	2	9	0	0.5	47	6	15	21
3	1.0	0.083	44	14	T	0	0	0	13	0	8	4	0	5	0	0.4	49	9	13	22
4	8.5	0.058	16	13	3	T	T	0	4	5	4	7	4	4	19(O)	0.3	101	42	9	51
5	6.5	0.057	52	13	T	0	0	0	3	2	4	10	0	T	3(P)	0.1	52	**	**	**
6	6.5	0.062	39	17	5	0	5	T	8	0	4	10	T	4	0	0.8	101	77	9	86
7	6.5	0.071	59	13	0	1	0	1	1	0	5	10	T	2	0	0.6	69	37	7	44
9	0.0	0.037	55	10	3	0	T	T	5	5	5	5	T	5	0	0.2	21	41	4	45
10	0.0	0.048	22	18	0	8	0	5	4	0	5	26	0	5	0	0.8	81	80	5	85

*A = quartz
B = feldspar
C = non-swelling layer clay
D = swelling mixed layer & montmorillonite
E = vermicolite
F = knelinite
G = chlorate
H = serpentine

I = mica
J = amorphous
K = organic
L = amphibole
M = miscellaneous
(N) = talc
(O) = volcanic slag
(P) = calcite

** = sample expanded when heated to 600°C
T = trace (less than 1%)

***Average Crack Frequency (per 100 lineal ft.)

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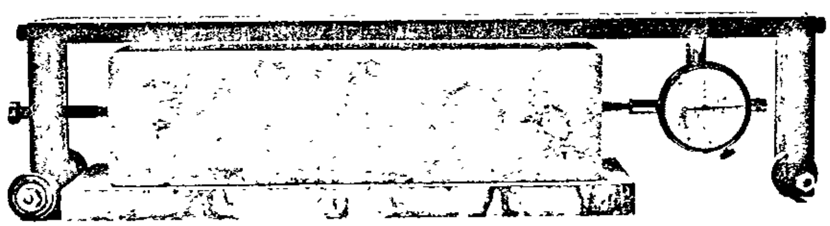
Shrinkage Test vs. Shrinkage Cracking

It was elected to use the ASTM procedure D1632-63, "Making and Curing Soil-Cement Compression and Flexure Test Specimens" to fabricate the CTB shrinkage specimens. These were 3" x 3" x 11 1/4" bars with gage pins cast into the ends. A similar method had been used by K. P. George to evaluate shrinkage of soil cement and cement treated base materials[4,5]. Cement content and specimen moisture and density were determined in reference to Test Method No. Calif. 312-D[6] which is used to prepare compressive strength specimens. The gradings of the selected aggregates were adjusted in the laboratory to meet the current California standard specifications for Class A CTB[7] and, where possible, closely duplicate the gradings of the cement treated bases actually placed during construction.

Following fabrication, the test specimens were left in the molds for 16 to 24 hours to develop enough strength to permit handling. They were then removed from the molds and placed in a curing room at 73°F and 100 percent relative humidity for six days, thus providing a total curing time of seven days. At the end of this arbitrarily selected seven day curing period, the length and weight of each specimen was measured. A dial comparator was used to measure initial specimen length as shown in Photo 2.

Photo 2



Shrinkage Specimen in Length Comparator

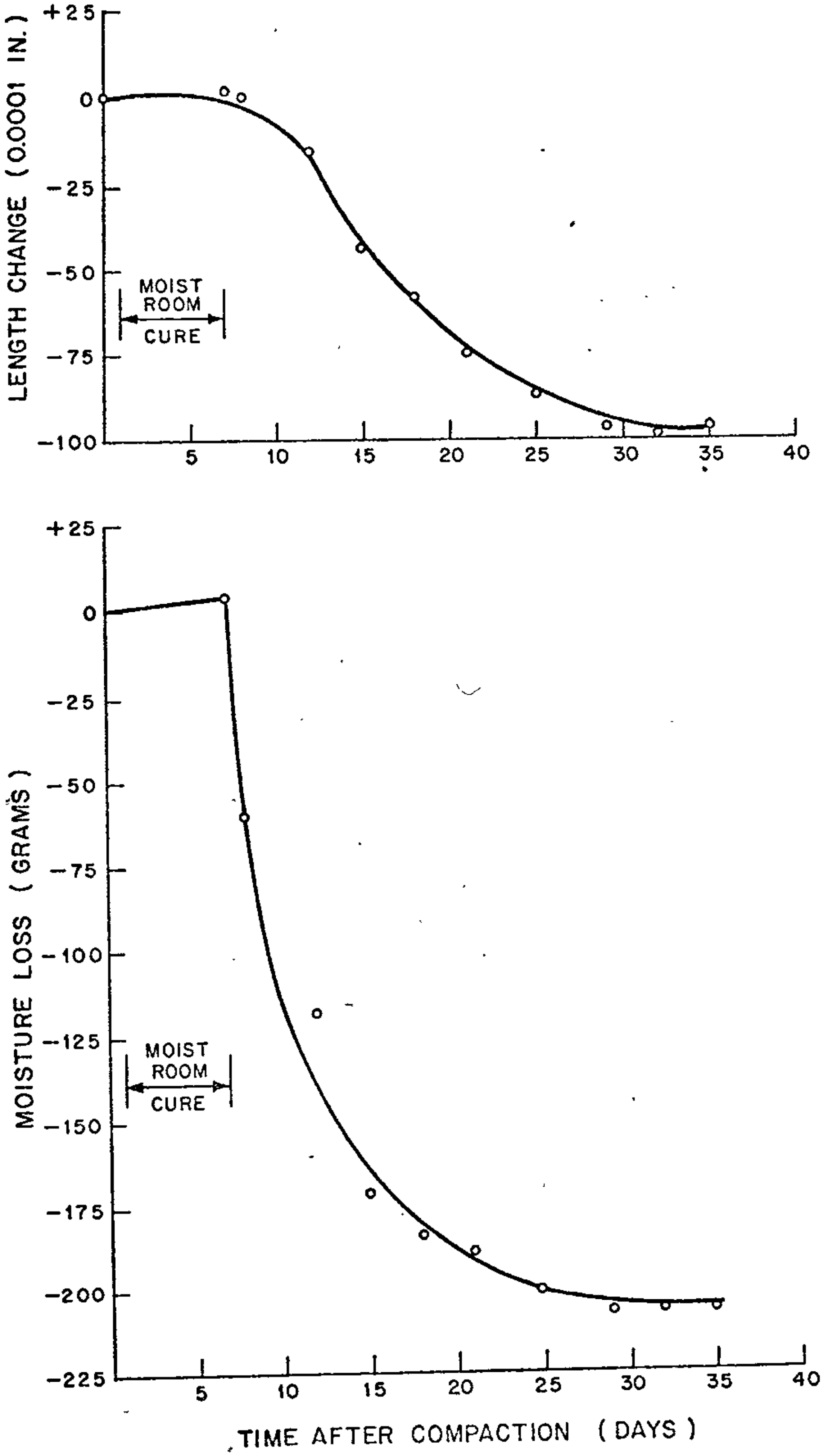
Several procedures for drying to induce shrinkage were tried; however, drying in an open laboratory oven at room temperature seemed to be as satisfactory as the more elaborate procedures tried. A twenty-one day cure was selected, as length-change and moisture loss was observed to be relatively stable by this time, Figure 1.

The eleven aggregates were tested for shrinkage and a "percent shrinkage" determined. This is calculated by subtracting the measured length after drying (28 days) from the measured length after the initial cure (7 days), and dividing the difference by the nominal gage length of 9.625 inches, or the net distance between the interior ends of the gage pins.

This shrinkage value was compared to the observed pavement cracking value previously associated with the aggregate.

The results are shown on Table 3 and Figure 2.

Figure 1

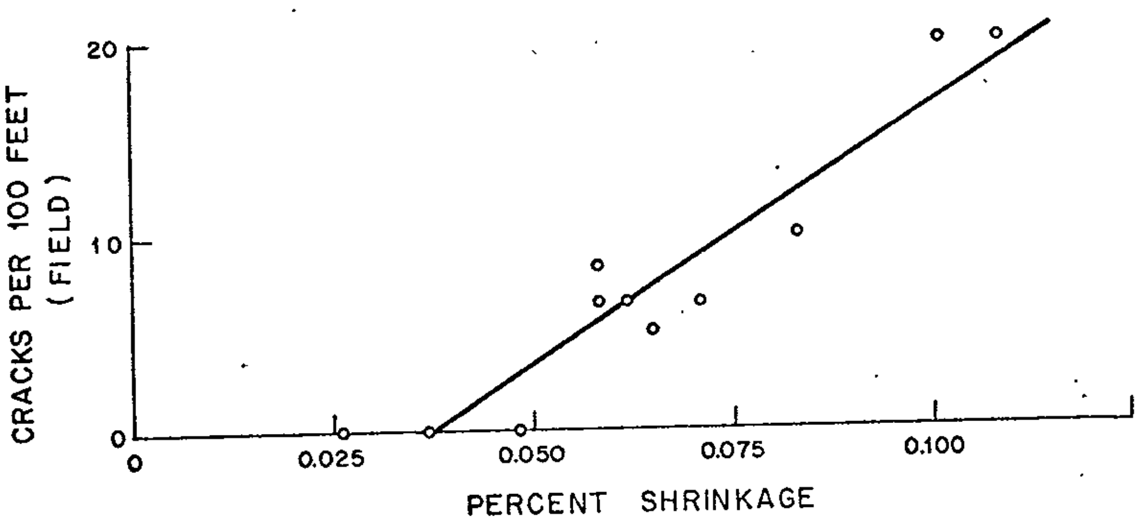


CTB SHRINKAGE AND MOISTURE LOSS WITH TIME

TABLE 3

Aggregate No.	Percent Shrinkage (28 Day Cure)	Observed Cracking (Cracks/100 ft.)
1	0.108	20.0
2	0.101	20.0
3	0.083	10.0
4	0.058	8.5
5	0.058	6.5
6	0.062	6.5
7	0.071	6.5
8	0.065	5.0
9	0.037	0
10	0.048	0
11	0.026	0

Figure 2



SHRINKAGE VS PAVEMENT CRACKING

This relatively good correlation between laboratory shrinkage and actual field performance was the basis for concluding that the procedure could be used to evaluate the potential shrinkage of cement treated base.

Design and Construction Variables

The results of the survey of the performance of CTB placed beneath flexible pavement in California[1] indicated that factors such as cement type, cement content, and relative compaction, within the range studied, had no significant effect on the frequency of shrinkage cracks reflected through the asphalt concrete. However, laboratory studies reported by other researchers have indicated that these factors, as well as excessive moisture, will significantly affect the shrinkage of soil cements[4,5,8,9]. To evaluate the effect that each of these variables has on shrinkage of CTB, comparative tests were run on several of the selected aggregates using one replica each. In each series of tests all the variables were held constant except the one being evaluated. Unless otherwise noted, the specimens tested contained 4 percent Type II modified cement and optimum moisture. They were compacted to 100 percent of the maximum density determined by Test Method No. Calif. 312.

Cement Type:

To evaluate the effect of cement type, duplicate portions of each aggregate were treated with Type I (ordinary) and Type II modified (moderate sulfate resistant) cements. The cement content, moisture content, and compaction were held constant for the tests. The measured shrinkage values are presented in Table 4.

TABLE 4
CEMENT TYPE VS. PERCENT SHRINKAGE

Aggregate No.	Percent Shrinkage: Type I Cement	Percent Shrinkage: Type II Cement
1	0.112	0.108
2	0.091	0.102
3	0.080	0.083
4	0.057	0.058
5	0.053	0.057
6	0.063	0.062
7	0.054	0.071
9	0.044	0.037
10	0.060	0.048
Average	0.068	0.070

There was no consistent relationship between the type of cement and the amount of shrinkage.

Cement Content:

To evaluate the possible effect that different amounts of cement might have on shrinkage, test specimens were prepared with 2-1/2, 4, and 6 percent cement using eight of the aggregates. These percentages were used since they represent the range normally used in California. The shrinkage values are presented in Table 5.

TABLE 5
CEMENT CONTENT VS. PERCENT SHRINKAGE

Aggregate No.	Percent Shrinkage At: 2-1/2% Cement	4% Cement	6% Cement
1	0.097	0.108	0.104
2	0.075	0.102	0.088
3	0.067	0.083	0.085
4	0.044	0.057	0.051
6	0.062	0.062	0.060
7	0.048	0.071	0.072
9	0.035	0.037	0.033
10	0.061	0.048	0.057
Average	0.061	0.071	0.068

It was concluded that variations in cement content, within the range of 2-1/2 to 6 percent, had no significant effect on the shrinkage of the material tested.

Density:

Table 6 illustrates the effect of density on the shrinkage potential of a cement treated base. Specimens were prepared with six aggregates and compacted to densities equal to 90, 95, and 100 percent of the laboratory determined maximum.

TABLE 6
RELATIVE COMPACTION VS. PERCENT SHRINKAGE

	Percent Shrinkage At:		
Aggregate No.	90% RC	95% RC	100% RC
1	0.097	0.098	0.108
3	0.097	0.082	0.083
5	0.057	0.051	0.057
6	0.078	0.065	0.062
9	0.041	0.035	0.037
10	0.058	0.067	0.048
Average	0.071	0.067	0.066

It appears that there is a systematic decrease in shrinkage with increased initial density. However, the effect is slight and not considered significant.

Moisture:

To study the effect of moisture variations, specimens were prepared with 4% cement at their optimum moisture content, and at moisture content 2% below and 2% above optimum. The test results are presented in Table 7.

TABLE 7
WATER CONTENT VS. PERCENT SHRINKAGE

	Percent Shrinkage At:		
Aggregate No.	-2%	Optimum Moisture	+2%
1	0.092	0.108	0.088
2	0.085	0.102	0.103
4	0.050	0.058	0.050
5	0.047	0.057	0.050
7	0.051	0.071	0.078
9	0.034	0.037	0.033
10	0.057	0.048	0.065
Average	0.059	0.069	0.067

In some instances, there was a noticeable difference in shrinkage between specimen containing different amounts of water. On the whole, however, it was concluded that these variations were not significant.

Chemical Additives

The effects of several chemical additives proposed to reduce shrinkage were investigated. These additives were added to the mixing water in the amounts shown on Table 8 prior to combining the aggregates, cement, and water.

Replicate portions of material, with and without the chemical additives, were tested in accordance with Test Method No. Calif. 312-E to determine the effect of the additives on density and compressive strength as well as for shrinkage. All of the specimens contained 4% Type II modified cement.

The results are shown in Table 8 and discussed as follows:

Hydrated Lime:

Hydrated lime was added to nine of the cement treated aggregates, and the effect on shrinkage was not consistent. Some materials showed decreases in shrinkage while others showed increases. The most substantial change was with aggregate No. 10. A shrinkage value is not shown for aggregate No. 4 which expanded excessively during the 7-day curing period and was longer after the drying period than when it was fabricated. Cracks also developed during the drying period. This aggregate contained volcanic slag, and also reacted adversely with two other additives.

The compressive strength of the specimens prepared with aggregate No. 9 decreased somewhat with the addition of lime, but for the most part the addition of lime caused no significant difference in the strength of any of the cement treated aggregates tested.

Density remained essentially unaffected, although the compacted density of CTB fabricated from aggregate No. 4 did decrease by about 4-1/2 pounds per cubic foot when lime was added.

Sodium Metasilicate:

Sodium metasilicate was added to representative portions of five of the cement treated base materials. As shown in Table 8, shrinkage was reduced for four of the five materials. Aggregate No. 4 again reacted with the addition such that by the end of the drying period the test specimen length still exceeded its original length.

TABLE 8

EFFECT OF CHEMICAL ADDITIVES ON CTB
MIX DESIGNS CONTAINING 4% CEMENT

AGGREGATE NUMBER	SHRINKAGE (Percent) A	B	C	D	E	F	G	COMPRESSIVE STRENGTH (PSI) A	B	C	D	E	F	G	DENSITY (PCF) A	B	C	D	E	F	G
1	0.108	0.112	-	-	-	-	-	835	-	-	-	-	-	-	132.6	-	-	-	-	-	-
2	0.102	0.094	0.074	0.083	0.072	0.110	0.095	977	1005 1085	750 920	995 955	875 925	1035 1155	980 1105	136.3	137.7 138.0	135.2 135.2	135.5 137.2	135.8 136.2	136.7 138.3	136.8 137.2
3	0.083	0.082	0.064	0.080	0.070	0.069	0.081	1177	1240 1260	910 915	1025 1195	980 1000	1066 1193	1203 1242	138.0	139.6 140.4	136.2 137.5	138.7 140.6	135.4 136.7	137.5 138.5	138.7 139.5
4	0.058	*	*	*	0.051	0.054	0.050	645	669 693	340 230	210 230	760 750	610 630	590 590	138.7	133.9 134.8	140.6 141.0	135.6 137.2	137.7 138.2	138.6 138.7	138.2 138.6
5	0.057	0.051	0.033	0.057	0.061	0.057	0.064	1275	1160 1420	960 935	1080 1100	755 860	1180 1370	1420 1435	137.6	139.7 141.1	136.2 136.5	137.0 137.0	133.8 135.2	136.1 139.2	140.2 140.7
6	0.062	0.071	-	-	-	-	-	755	749 820	-	-	-	-	-	127.0	128.0 128.0	-	-	-	-	-
7	0.071	0.060	0.047	0.071	0.040	0.068	0.075	1115	1140 1185	670 740	900 1042	860 430	1225 1265	1235 1160	134.9	134.6 136.2	130.2 130.4	134.7 135.8	129.3 131.0	137.2 138.5	134.7 135.0
9	0.037	0.025	-	-	-	-	-	875	669 693	-	-	-	-	-	134.6	133.9 134.8	-	-	-	-	-
10	0.048	0.070	-	-	-	-	-	1100	1085 1270	-	-	-	-	-	127.6	129.0 129.0	-	-	-	-	-
Avg. (Nos. 2,3,5,7)	.078	.072	.054	.073	.061	.076	.079	1136	1187	850	1040	898	1186	1222	136.7	138.4	134.7	137.1	134.2	137.8	137.8

* = excessive expansion occurred during curing period
A = untreated
B = hydrated lime, (88% $Ca(OH)_2$), 1% by dry wt. of aggregate
C = sodium metasilicate, (Na_2SO_3 $9H_2O$) 1% " " " " "
D = sodium aluminate, (Na_2O Al_2O_3 $3H_2O$) 0.1 " " " " "
E = potassium silicate, (K_2SO_3) 1% " " " " "
F = lignosulfonic acid, (Zeecon R-40) 8 oz/94 lbs of cement
G = hydroxylated carboxylic acid, (Plastocrete A) 2 oz/94 " " "

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The observed decreases in shrinkage with aggregate Nos. 2, 3, 5, and 7 were accompanied by significant decreases in compressive strength. The average decrease was approximately 25%. The densities also decreased slightly.

A supplemental series of strength and density tests was run using one aggregate and reduced amounts of sodium metasilicate. The results indicated that even a reduced amount of the additive may also decrease compressive strength noticeably.

Sodium Aluminate:

Sodium aluminate was used as an additive with five of the cement treated base materials. As shown in Table 8, this additive had little effect on shrinkage. It did, however, measurably reduce the compressive strength of three of the CTB mixes. The mix containing aggregate No. 4 showed the greatest loss of strength, decreasing by approximately 67%.

Supplemental tests, using amounts of sodium aluminate ranging from 0.1 to 1.0 percent, were run using aggregate No. 2 to determine the effect of increased concentrations of the sodium aluminate. The results indicate that varying the concentration of the sodium aluminate between 0.1 and 1.0% had no consistent effect on the density of the CTB but did noticeably affect compressive strength.

Potassium Silicate:

Potassium silicate tended to reduce the shrinkage of the cement treated aggregates. However, there was also a decrease in compressive strength, with the exception of aggregate No. 4 which contains volcanic slag. For example, the strength of the mix containing aggregate No. 5 was reduced by more than 36% when the additive was used. This decrease in strength was associated with a reduction in density of as much as 3.1 lbs. per cu. ft.

Lignosulfonic Acid:

Lignosulfonic acid, when added at the manufacturer's recommended rate of 8 oz/94 lbs of cement, had little influence on the shrinkage of any of the five aggregates tested. The densities and compressive strengths also remained generally unaffected with the exception of the mix containing aggregate No. 7. The density of this CTB increased about 3 lbs. per cu. ft. This was accompanied by a slight increase in compressive strength.

Hydroxylated Carboxylic Acid:

Hydroxylated carboxylic acid, when added at the manufacturer's recommended rate of 2 oz./94 lbs. of cement, had no consistent influence on any of the three measured properties. The density of the CTB containing No. 5, however, did increase somewhat. This increase was accompanied by a slight increase in compressive strength.

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